INCOHERENT SCATTERING OF 280 KEV GAMMA RAYS

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ABSTRACT Incoherent scattering cross-sections σ_b in elements carbon, aluminium, copper and cadmium are determined at the photon energy 280 kev and compared with the corresponding Klein-Nishina cross-section σ_f. Progressively increasing deviation is observed between the two cross-sections with increasing atomic number. This deviation is attributed to the influence of electron binding. The ratio (σ_b/σ_f) is computed theoretically on the basis of Thomas-Fermi atomic charge distribution and compared with the experimentally observed ratio. A fair agreement is noticed.

INTRODUCTION

It is well-known that the incoherent scattering of photons by free electrons is accurately described by Klein-Nishina theory. Atomic electrons can be considered as free if the incident photon energy greatly exceeds the binding energy of the electrons in the atom. When this condition does not obtain, the cross-section for incoherent scattering will be smaller than predicted by Klein-Nishina formula. This diminution in the incoherent scattering cross-section due to electron binding effects is expressed in terms of an incoherent scattering function which is dependent on the momentum transferred to the electron and the atomic number of the scattering medium. Various models of atomic charge distribution are in use to compute the incoherent scattering function theoretically.

It was shown experimentally by Lakshminarayana *et al* (1961) that the 'free electron assumption' holds for light elements at incident photon energies greater than 662 kev. Detailed investigations by Motz *et al* (1961) on the Compton scattering of 662 kev photons by the K-shell electrons of tin and gold have shown that even in these elements atomic binding effects are negligible at this energy. However, at lower energies, definite deviations from Klein-Nishina cross-section due to binding effects are qualitatively indicated even for light elements in the work of Lakshminarayana *et al.* The present investigation is an attempt to assess the influence of electron binding in light elements in a quantitative manner at the photon energy 280 kev.

A simple procedure is adopted to obtain the incoherent scattering cross-sections experimentally. The method consists of determining the total atomic cross-section by transmission experiments and subtracting from it the theoretically computed contributions due to photoelectric and coherent scattering processes. To achieve sufficient accuracy in this 'subtraction technique', the light elements C, Al, Cu and Cd are chosen as the scattering materials in as much as the theoretical computation of photoelectric and coherent scattering cross-sections can be carried out to the desired degree of accuracy in light elements.

EXPERIMENTAL DETAILS

A 10 milli-curie mercury—203 source is used to provide the 280 kev gamma rays. A modified narrow-beam geometry identical with that described by Lakshminarayana *et al* (1961) is employed. A Du Mont 6292 photomultiplier with 3/4″×3/4″ NaI(Tl) crystal is used as the detector. The experimental procedure as well as the method of analysis of obtaining total atomic-cross-sections is just the same as of Lakshminarayana *et al.* The cross-sections are determined with a standard deviation not exceeding 1% in the present investigation.

The photoelectric cross-sections are computed to within an accuracy of 2% using Nagel's formula (1960) whose applicability to low and medium Z elements is established by Parthasarathi, *et al* (1964). The coherent scattering cross-sections are estimated to within an accuracy of 3% making use of the form-factor formalism whose validity is established in the low energy region for light elements.

By subtracting the sum of photoelectric and coherent scattering cross-sections from the total atomic cross-section, the experimental value of the incoherent scattering cross-section σ_b is deduced. The values of σ_b for the various elements are given in column 2 of Table 1. For comparison, the corresponding free electron

TABLE I

Element (1)	σ_b (in barns/atom) (2)	σ_f (in barns/atom) (3)	(σ_b/σ_f) Exptl. (4)	(σ_b/σ_f) Theor. (5)
Carbon	2.12 ± 0.02	2.18	0.98 ± 0.01	0.98 ± 0.03
Aluminium	4.55 ± 0.05	4.72	0.97 ± 0.01	0.97 ± 0.03
Copper	9.80 ± 0.1	10.53	0.93 ± 0.01	0.95 ± 0.03
Cadmium	15.7 ± 0.4	17.4	0.90 ± 0.02	0.92 ± 0.03

cross-sections σ_f are computed using Klein-Nishina formula and are given in column 3 of Table I. The values of cross-section given in column 2 refer to the incoherent scattering of photons by all the electrons of the atom integrated over all angles of scattering. The values of cross-section given in column 3 of Table I are obtained by multiplying the integral free electron cross-section by the atomic number. The ratio $(\sigma_b/\sigma_f)_{exptl}$ given in column 4 provides a quantititative estimate of the influence of atomic binding on the incoherent scattering of 280 kev gamma rays. A theoretical estimate of this ratio is made using the Thomas-Fermi atomic charge distribution. The relevant procedure is outlined as follows : Data on the incoherent scattering function $S(q, Z)$ as a function of universal variable v are complied by Grodstein (1957) and Nelms (1953). The differential Compton scattering cross-sections for a free electron are computed using Klein-Nishina formula at various scattering angles, at intervals of 10°, in the range 0° to 180°. The value of $S(q, Z)$ corresponding to each of these scattering angles is obtained by graphical interpolation of the data complied by Grodstein and Nelms. The differential free electron cross-section is then multiplied by the corresponding $S(q, Z)$ to yield the differential cross-section for bound electron scattering. By a graphical integration of these free electron and bound electron differential cross-sections in the angular interval 0° to 180°, the corresponding integral cross-sections are computed and the ratio $(\sigma_b/\sigma_f)_{theor}$ is then directly obtained. The overall error involved in the interpolation and integration procedures is estimated to be about 3%. These theoretical ratios are presented in column 5 of Table I.

RESULTS

It can be seen from columns 2 and 3 of Table I that the bound electron cross-sections progressively deviate from the free electron cross-sections. The increasing influence of atomic binding as Z increases is clearly evident. From the values of $(\sigma_b/\sigma_f)_{exptl}$ in column 4 of Table I, it can be readily seen that the diminution in the free electron cross-section due to binding effects is $(2 \pm 1)\%$ for C, $(3 \pm 1)\%$ for Al, $(7 \pm 1)\%$ for Cu and $(10 \pm 2)\%$ for Cd.

A comparison between theory and experiment is provided by the values given in columns 4 and 5 of Table I. It is apparent that there is good agreement between theoretical and experimental values of the ratio (σ_b/σ_f). This agreement, however, has to be considered with some caution in view of the inadequacies of the Thomas-Fermi model for observed distribution. The charge agreement may be due to the fact that at this energy the absolute magnitude of the influence of binding is itself small, so that the deviations, if any, are masked by the combined errors of theory and experiment. It may, however, be possible that the deviations might be noticeable at lower photon energies where the diminution of σ_f due to binding effects will be considerably large. Further investigations at lower photon energies are in progress to test this view-point.

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